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A Model of the Effects of Acceleration on a Pursuit Tracking Task

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NOTICES

TECHNICAL REVIEW AND APPROVAL

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Instruction 40-402.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR

//Signed//

MARK M. HOFFMAN
Deputy Chief, Biosciences and Protection Division
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14. ABSTRACT
Flight in fast fighter aircraft often results in physiological decrements caused by high accelerations due to gravity (Gz). Of principal importance during combat is the pilot's ability to track a moving target during high Gz maneuvers. A mathematical model of this task could become useful when planning air combat missions. Eight subjects performed a 2-D manual pursuit tracking task during four different Gz conditions in a human centrifuge simulator. The conditions included a 3Gz, 5-Gz, and 7-Gz profile with one 15-sec peak. The final profile was a 7Gz peak simulated aerial combat maneuver (SACM). Time, Gz, and root mean square error (RMSE) were recorded. A modeling program was then created that accepted the time history of a Gz profile as input and used the values to calculate changes in the tracking RMSE values. The Gz profiles were then examined for agreement. The correlation coefficient, linear best-fit slope, and mean percent error were calculated for each Gz condition. Results: Correlation coefficients, linear best fit slope, and mean % error were as follows: 5Gz (0.91, 1.04, 6%), 7Gz (0.96, 0.99, 7%), and 7Gz SACM (0.82, 0.78, 8%). The 3 Gz predicted and measured output was a relatively constant RMSE value of 72. Conclusions: The model is a reasonable predictor of average RMSE values during a pursuit tracking task for Gz levels between 3 and 7 in a human centrifuge.

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High G, Pursuit Tracking, Acceleration

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PREFACE

The work covered in the following report was completed under the Human Information Processing in Dynamic Environments (HIPDE) program. The project/task/work unit number is 71840303. The program manager for HIPDE is Capt. Kathy Fullerton (AFRL/HEPG). The work covered in this report began in October of 2002 and was completed in September of 2004. It covers the results of a gunsight pursuit tracking task in the centrifuge and the corresponding modeling work. This is the first of twelve performance tasks to be completed under this program.

This project would not have been possible were it not for the expert technical support contributed by several sources. First, the authors would like to thank the Dynamic Environment Simulator (DES) operations crew for their support in running subjects in the centrifuge during this experiment. In addition, significant contributions were made by NTI, Inc. by identifying the critical cognitive skills needed in the flight environment.

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A MODEL OF THE EFFECTS OF ACCELERATION ON A PURSUIT TRACKING TASK

INTRODUCTION

The ability to proficiently maneuver the aircraft is arguably the most critical skill for aircrew to maintain to achieve mission success. However, modern high-performance fighter aircraft are capable of reaching accelerations that exceed the limits of human physiology. Consequently, task performance and decision-making abilities can be seriously impaired during tight turns or other high-acceleration maneuvers due to the stress of the inertial environment. Decreases in eye-level blood pressure and cerebral oxygen saturation (rSO_2) lead to decreased motor function and cognitive ability (**2, 8, 10**). Human cognition encompasses such processes as thought, perception, problem solving, and memory. These resulting deficits can seriously impede the pilot's ability to successfully navigate the aircraft and track targets.

Cognitive ability is likely interrelated with the amount of available oxygenated blood. The brain requires an exorbitant amount of oxygen to function properly. In fact, the brain receives about 15-20 percent of the body's total blood supply, thus 15-20 percent of the total amount of inhaled oxygen. The principal reason for this is that the brain cannot metabolize fat or carbohydrates for energy. Neurons typically utilize only glucose for energy. Glucose is converted to usable energy by combining with oxygen to form adensoine triphosphate (ATP) molecules through a three-phase process that includes aerobic glycolysis, the Kreb's Cycle, and the electron transport chain. In total, every molecule of glucose can yield a maximum of 38 ATP molecules when oxygen is readily available. However, anaerobic glycolysis produces a total of only two ATP molecules for each molecule of glucose, or about 5% as much energy.

Neurons require large quantities of energy for several functions. First, neurons do not reproduce and therefore must expend considerable amounts of energy to repair or replace various cell components to ensure they survive the lifespan of an individual human being. In addition, neurons must use ATP to package, transport, produce, secrete and reuptake neurotransmitters. Lastly, they consume massive amounts of energy to transmit electrical energy (action potentials) from the dendrites, through the cell body, to the axon.

The force upon an object due to the earth's gravitation pull is the acceleration due to gravity multiplied by the mass of the object. This acceleration is commonly denoted by the letter G. An increase in acceleration in the z-axis (head-to-foot) likewise increases the force acting upon the body and causes an increase in the apparent weight of the blood. As this apparent weight continues to increase, the heart must work harder and harder to overcome this added force and pump the blood to the upper extremities, including the head. Each additional $+1G_z$ applied translates into a 22 mmHg decrease in eye-level blood pressure (**6**). Once the apparent weight of the blood exceeds the ability of the cardiovascular system to generate compensating pressure, the flow of blood in the intracranial arteries significantly decreases, consequently causing the blood to pool in the lower extremities and reducing oxygenated blood flow to the cerebral tissues (**2**). Without adequate oxygen, the brain cannot produce enough energy (ATP molecules) to sustain all cognitive processes. Therefore, many of the higher-order cognitive functions

begin to dissipate or arrest all together so that critical functions (such as breathing) can be maintained. A detailed investigation of the extent to which cognitive performance is affected by increases in acceleration is therefore necessary to attain a complete understanding of the overall pilot performance and effectiveness for a given mission.

Acceleration research has been conducted for well over fifty years, and in that time much has been learned regarding the effect of the high-G environment on the human body and the resulting changes in physiology. These efforts have aided in the understanding of the principal phenomena that affect vision, endurance, consciousness, and performance, while leading to the development of superior G protective measures such as advanced G-suits and anti-G straining maneuvers. Still, the effects of acceleration stress on cognitive performance are largely unknown. Although several studies have been conducted that examine task performance, relatively few have been accomplished that probe the level of degradation in specific cognitive skills (**1, 3, 5, 7, 9, 13, 14, 15**). Furthermore, until now, virtually no emphasis has been placed on providing predictive tools or models that could yield pilot task performance decrements based on the decreased cognitive ability at higher accelerations.

The program entitled, "Human Information Processing in Dynamic Environments" (HIPDE) has been created to provide constructed representations of fighter pilots to the modeling and simulation (M&S) community that include validated algorithms to modify the agents' performance and cognition based on the stress of the inertial environment. The first goal of the HIPDE program concerns the development of a custom task battery to probe specific cognitive functions. This work was completed by NTI, Inc. (Dayton, OH), who identified twelve critical cognitive skills required in the flight environment through discussions with pilots.

NTI, Inc. also developed software containing twelve performance tasks that can be used to probe these cognitive skills. Many of the tasks focus on probing the performance of a particular cognitive skill; however, they actually test several other cognitive abilities to a lesser extent. Therefore, subject matter experts (SME's) were consulted to determine the extent to which each skill is tested in each of the twelve performance tasks. The SME's rated the level at which each of the cognitive skills is used for each of the twelve tasks with a value between 0 and 9 (9 corresponds to a cognitive skill that is highly used in the task, 0 represents a skill that is not used at all). A matrix was created from these values that can be used to weight the performance data recorded from acceleration studies across the twelve critical cognitive skills. The performance for each of the twelve tasks identified by NTI, Inc. will be studied separately during various G_z profiles. The results of each of these studies will be mathematically modeled, weighted, and then integrated into a larger cognitive performance model. The present study is essentially the first step to creating this larger model and addresses performance on the first cognitive task, tracking. The final goals are to integrate the large cognitive performance model into existing pilot simulation software and participate as a case study in simulation exercise.

METHODS

Subjects

Eight active duty members of the United States Air Force (one woman and seven men) volunteered to participate in the study. They ranged in age from 28 to 38 years, with a mean age of 32 years. All participating subjects were members of the sustained acceleration stress panel at Wright-Patterson AFB, OH. As part of the requirement for membership on the stress panel, all participants completed the Air Force's extensive centrifuge G-training program to ensure that their tolerance to acceleration and their vestibular responses under acceleration were similar to those of pilots flying high-performance aircraft.

In order to qualify for service in the study, each subject had to meet Air Force flying class III medical, height, and weight standards and have no history of neurological pathology. In addition, all participants were required to have normal or corrected-to-normal vision and a normally functioning vestibular system. Information about these qualifying factors was obtained from screening the participant's medical records. Prior to final acceptance into the study, all participants underwent a rigorous physical examination including x-rays of the skull and spine, tests of the integrity of the cardiovascular, pulmonary, and nervous systems, and a comprehensive blood chemistry work-up. On the basis of this examination, all participants were determined to be in excellent health by a flight surgeon.

Facilities

All training and data collection for this study was performed at the Air Force Research Laboratory's Dynamic Environment Simulator (DES) centrifuge facilities at Wright-Patterson AFB (Figure 1).

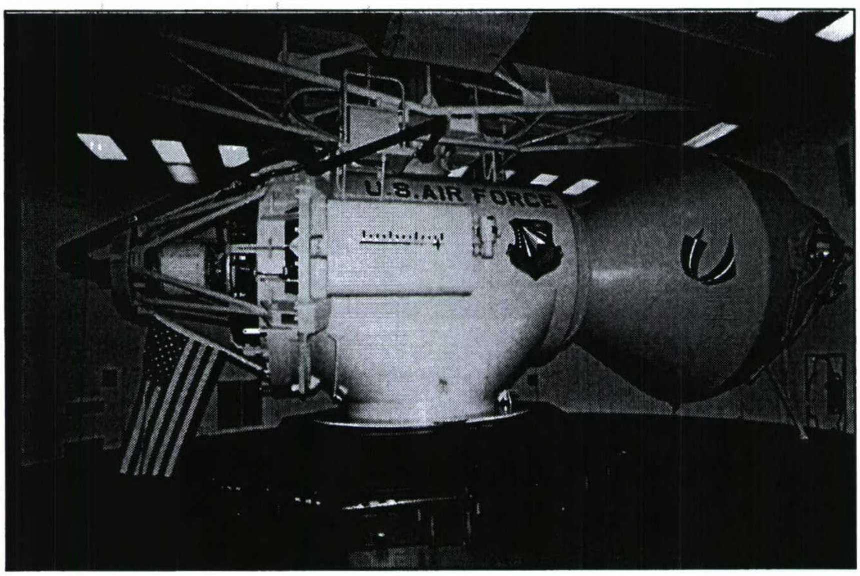

Figure 1. Dynamic Environment Simulator
Wright-Patterson AFB

The DES is a human-rated centrifuge with an arm radius of approximately 19 feet. It is capable of attaining and sustaining accelerations up to 20 G in one of three independent axes: x, y and z. The DES has a maximum G onset and offset rate of approximately 1 G/sec. The gondola of the centrifuge was equipped with an F-22-like ACES II ejection seat with a seatback reclined to 15° from vertical. As illustrated in Figure 2, the seat had adjustable lap and shoulder restraints.

An aircraft IC-10 communication system was used to provide two-way voice communication between the research participant and the investigator. The participant's microphone was fixed in the open position to allow the participant "hands-free" communication. Participants were also provided with an emergency abort switch that enabled them to stop the centrifuge at any time during testing. Participants wore a standard Air Force issue Nomex® flight suit and a standard G-suit during all testing runs.

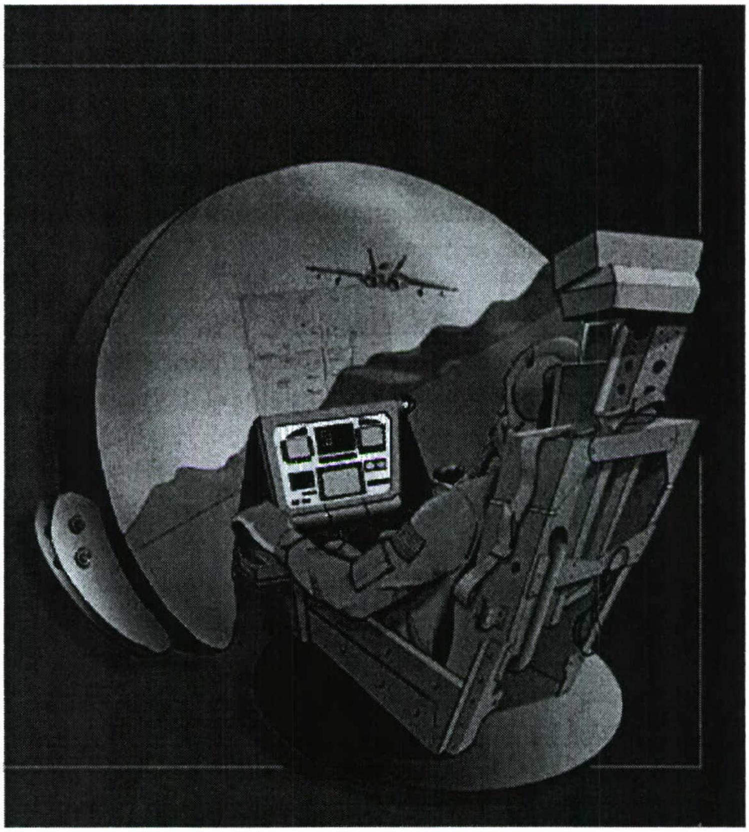

Figure 2. Illustration of ACES II Ejection Seat with Hotas Thrustmaster Flight Stick and Throttle with Dome Visual Display

The gondola was outfitted with a simulated fighter cockpit. The cockpit incorporated a Thrustmaster Hotas Cougar flight stick (Guillemot, Montreal, Canada) mounted on the participant's right side, and a corresponding throttle control mounted on the participant's left side. This was used to secure responses to the tracking performance task. A six-foot hemispherical shell viewing screen, representing a 130° (vertical) x 180° (horizontal) visual field, mounted directly in front of the participant, was used to display the terrain. A separate projector was used to display the head-up display (HUD) in the

center of the subjects' field-of-view. In addition, a 23-inch (diagonal) LCD screen was used to display the instrument panel. Figure 3 illustrates the entire visual display.

Continuous surveillance of participants was provided by two closed-circuit infrared television cameras. The cameras offered a close-up view of the participant's head and a wide-angle view of the participant from head-to-foot. Research personnel housed in a control room observed the video images. A video mixer was used to generate a composite picture of the two views of the participant along with the time, date, electrocardiogram (ECG) data, and G_z acceleration in a given run. Video data were stored on ½ inch VHS videotape for later analysis.

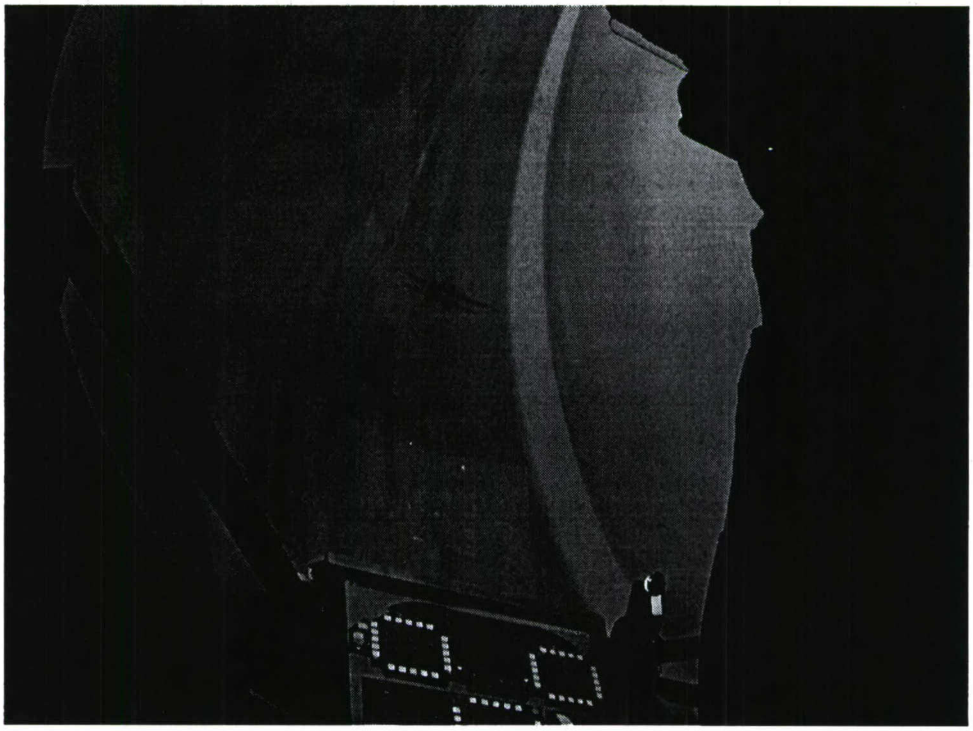

Figure 3. Hemispherical Shell Viewing Screen

Acceleration Profiles

A total of four G_z acceleration profiles were generated for use in this study. All G_z exposures were started from a baseline acceleration of 1.5 G_z. The first three profiles were comprised of a 1 G/sec onset ramp to a 15-sec plateau followed by a G_z offset ramp of 1 G/sec down to the baseline acceleration level. The plateaus were 3, 5, and 7 G_z, respectively. The final acceleration exposure was a simulated aerial combat maneuver (SACM). This profile consisted of two 5-sec G_z peaks to 7 G_z with several intermittent peaks to 3 and 5 G_z. Figure 4 displays an example of a G_z plateau profile, while Figure 5 presents the SACM profile.

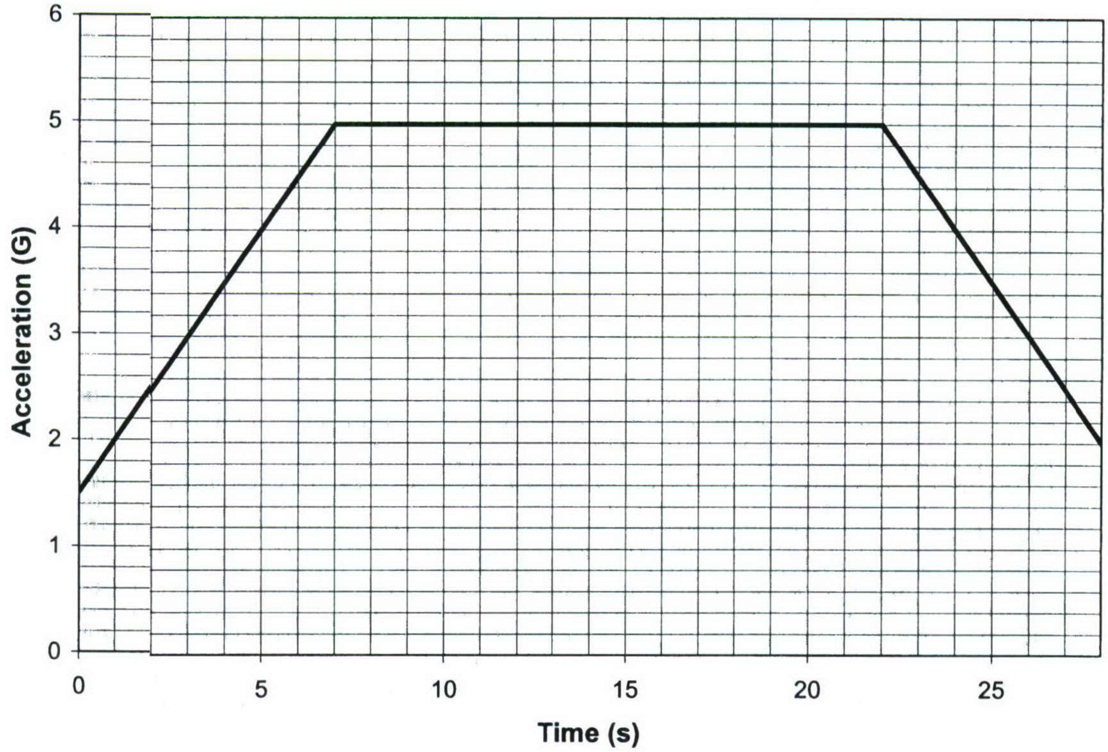

Figure 4. 15-sec G_z Plateau Profile Example (5 G_z)

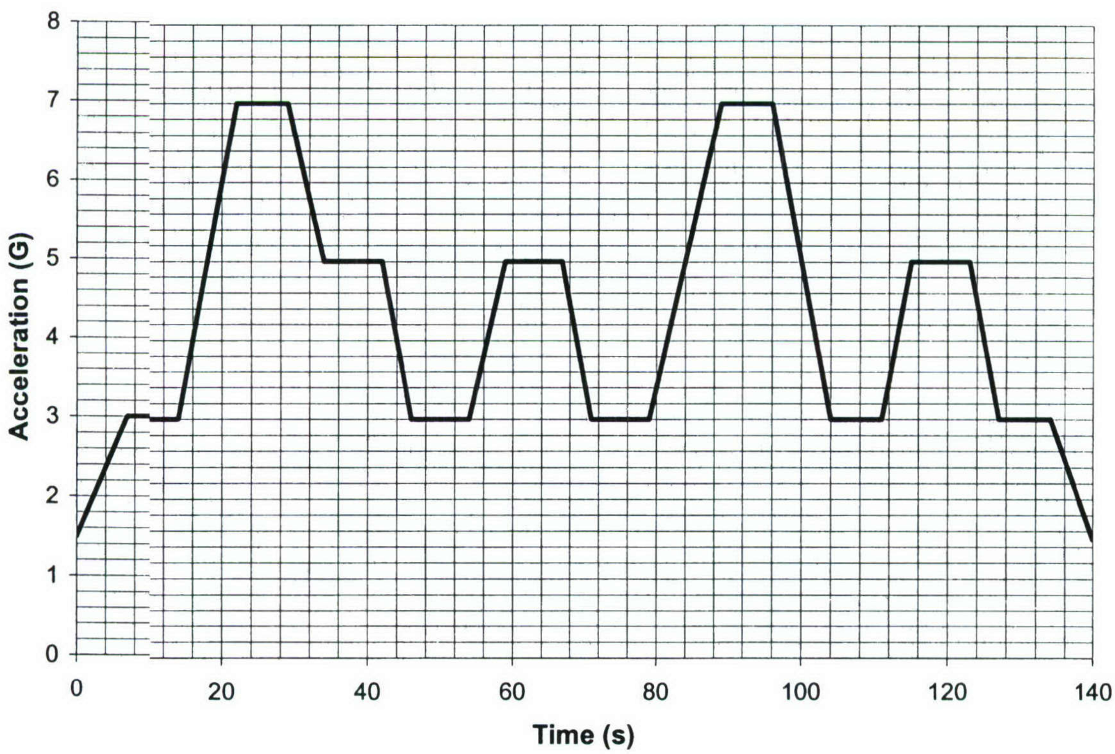

Figure 5. 7 G_z SACM Profile

Performance Task

A pursuit tracking task was created to evaluate the subjects' ability to successfully track a target in varying G_z environments. A simulated SU-37 flew a random flight profile that included left and right turns varying between 4.5 and 7 G_z. This target aircraft was placed under several restraints to reduce the overall difficulty of the task. First, the altitude was limited to a range of 1,500 to 10,000 ft. In addition, the target was tied to the subjects' aircraft to limit the maximum distance between the two jets. An additional restraint was placed on the task that set the subjects' airspeed to 470 knots. The task software calculated the root-mean-square error (RMSE) between the target and the subject aircraft at a sample frequency of 32 Hz. In addition, G_z and time data from the centrifuge were recorded in the same data files for later analysis.

Static Training

All subjects were trained statically on the performance task prior to dynamic training and experimental data collection. Static training was performed in an F-16 mock-up fuselage equipped with an ACES II aircraft seat with a 15-degree seatback angle. The task was projected onto a 48-in. (vertical) x 64-in. (horizontal) screen. Subjects performed the task for three minutes followed by a one-minute rest period. This was repeated three times per static training day. An average RMSE score was calculated by the tracking task software for each three-minute interval. The subjects were considered trained once their average RMSE score deviated less than 10% between training days.

Procedures

On a typical experimental test day, participants arrived at the laboratory, donned a flight suit and a standard G-suit, and were instrumented with electrocardiogram leads. The flight surgeon performed a brief medical examination and reviewed the subject's medical history. The participant then proceeded to the centrifuge where he/she donned a parachute harness. After entering the gondola of the centrifuge, the participant was secured to the ACES II aircraft seat (with a 15-degree seatback angle) using a three-point aircraft restraint system. The ECG leads were connected and the signals were verified prior to securing the gondola of the centrifuge. At this point, the tracking task was started and baseline performance data were collected for 3 min. Following the collection of baseline data the participant experienced his/her first G-exposure.

The subject experienced each of the four G_z exposures on three different test days in the following order: 3 G_z 15-sec plateau, 5 G_z 15-sec plateau, 7 G_z 15-sec plateau, and 7 G_z SACM. The subject began the tracking task approximately 8 sec prior to each G_z exposure and continued for approximately 8 sec after the acceleration had returned to the baseline G_z level of 1.5 G_z. A 1-minute rest period was provided between each G_z exposure, during which the task was not performed and the subject was permitted to relax at the baseline G_z level. This was accomplished to allow the physiology to return to the pre-acceleration exposure levels. Following the completion of the four G_z exposures, the participant egressed the centrifuge and was immediately examined by the flight surgeon and then released to return to his/her normal duties. These procedures were repeated over three experimental test days.

Model

A computer-based model of tracking performance under $+G_z$ stress was created using Microsoft Visual C++ 6.0. The time and G_z data from the four G_z exposures were

used as input for the model. The program was designed to retrieve these data from the input data files and then prompt the investigator for the total number of data points in the input file. The software used this number to determine when to stop the output of data to the output file.

The model updated the time and G data individually point-by-point. For each of these points, the software first determined whether the G_z data were increasing, decreasing, or had reached a plateau. This was accomplished by comparing each datum point to the previous one. If the new datum point was larger than the previous, then G_z was determined to be increasing. Likewise, if the new datum point was smaller than the previous, then G_z was determined to be decreasing. If they were equal, the G_z was determined to have reached a plateau. The program used simple if-then-else logic to make the determination.

If the G_z was concluded to be rising, the software then used exponential equations of the form found in Equation 1 below to calculate the root-mean-square error (RMSE) between the subject's gun-sight crosshairs and the target aircraft. Conditional statements, utilizing if-then-else logic, were constructed to monitor the G_z level, the number and magnitude of previous peaks, and the time at G_z.

Equation 1: $$RMS = C_1\left[e^{(0.7 \bullet G_z)}\right] + \left[rSO_2 + C3\right]$$

where:

Equation 1.1: $$C_2 = -1.0103G_z + 100$$

Equation 1.2: $$rSO_2 = -1.1598G_z + 71.191$$

Equation 1.3: $$G_{factor} = 10.933G_z + 60.015$$

and:

Equation 1.4: $$C_3 = C_2 - G_{factor}$$

In Equation 1.0, C_1 is a value between 1.0 and 0.7 that is determined by the G_z level. That is to say, C_1 decreases as G_z increases. The G_z level and, thus, the value of C_1 are determined with if-then-else conditional statements.

If the software detected that a plateau had been reached, simple linear equations of the form found in Equation 2 were used to modify the RMSE data.

Equation 2: $$RMS = RMS(t-1) + D$$

In this equation, the constant denoted as D is a value between 0.1 and 0.53. This value is dependent on the time at G_z, the current value of G_z, and the number and magnitude of previous peaks. Here a higher value of D would be consistent with higher G_z levels, a higher number of previous high magnitude (7 G_z) peaks, and/or extended periods at G_z. The value was set according to the corresponding if-then-else conditional statements that were satisfied at that specific time point.

Finally, if the G_z values were determined to be decreasing, the software used linear equations of the form found in Equation 3 to determine RMS values.

Equation 3: $$RMS = RMS(t-1) - E$$

Here, the value denoted by the variable E ranged from 0.2 to 1.5. This value varied with G_z level, number and magnitude of previous G_z peaks, and time at G_z, which were all determined using the if-then-else logic.

Data Analysis

For the post hoc analysis, the tracking RMSE data were determined approximately every 4 seconds. The value of 4 seconds was used due to the fact that it eliminated much of the noise in the signal and yet represented gross changes in performance. These RMSE data values were then logged for analysis to account for the positive skewing associated with tracking data. The data were then averaged across subjects and then across subjects and replications. The latter was used in the development of the model. The data were later transformed into percent change from the baseline values.

Next, tracking RMSE data were converted into values that represent the proportion of time that the target aircraft was closely tracked by the subject. The target aircraft was determined to be outside acceptable range limits once the RMSE score deviated more than 10% from the average baseline RMSE score. A value of one was assigned to RMSE values outside this limit and a zero was assigned to RMSE values within the limit for each data point. Therefore, values close to 0 signify that the target aircraft is within a reasonable shooting range, whereas values closer to 1 refer to the situation where the target is out-maneuvering the subject's aircraft. The proportion data were then averaged across subjects and replications.

Agreement between the measured data and the model predictions was determined using criteria established by Griffin (**4**). Griffin defines good agreement as having three qualities. First, the data must have a correlation coefficient close to one. However, high correlation is not enough to determine overall agreement. "A high correlation between measured and predicted values can be achieved with a poor agreement between the two values. For example, if measured values are exactly half the observed values, the correlation is still perfect." (**4**) Therefore, the model must also have a linear best-fit slope close to one, on a plot of measured vs. predicted values, and low mean percent error. The combination of these the quantities can be used to show the level of agreement (**4**).

RESULTS

The collected RMSE tracking data were first averaged across subjects. A plot of these results from the 3, 5, and 7 G_z plateau profiles is included in Figure 6 below.

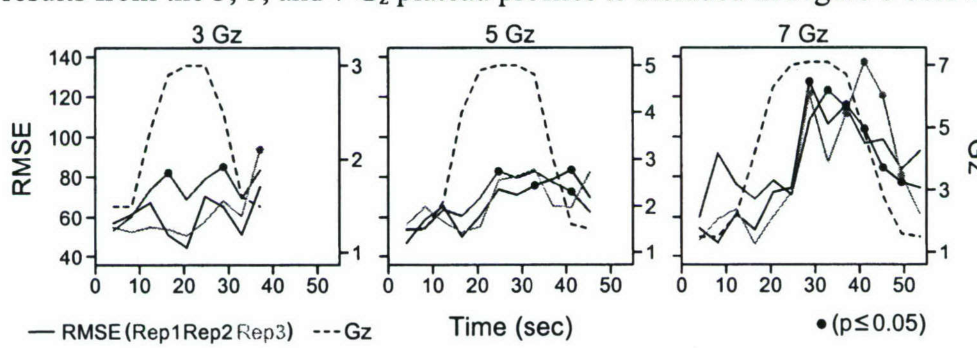

Figure 6. RMSE for Each G_z Plateau Averaged Across Subjects

Next, the data were averaged across subjects and replications. This is illustrated in Figure 7.

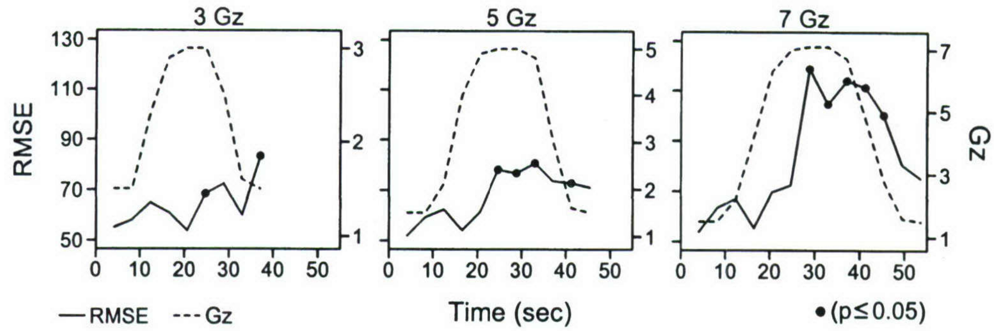

Figure 7. RMSE for Each G_z Plateau Averaged Across Subjects and Replications

RMSE tracking data collected during the 7 G_z SACM were also averaged across subjects and replications. The resulting plot can be found in Figure 8.

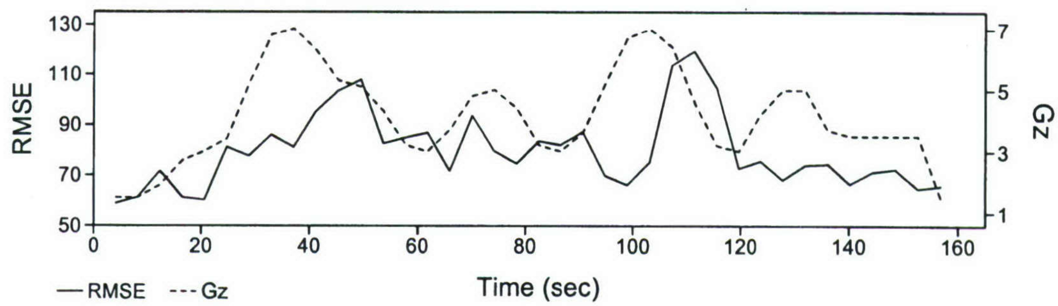

Figure 8. RMSE during SACM Averaged Across Subjects and Replications

The RMSE tracking data were then converted into values that represent the proportion of time that the target aircraft was closely tracked by the subject. The target aircraft was determined to be outside acceptable range limits once the RMSE score deviated more than 10% from the average baseline RMSE score. The proportion data were first averaged across subjects. The results from the 3, 5, and 7 G_z profiles are plotted in Figure 9. These data were then averaged across replications and the resulting plots can be found in Figure 10.

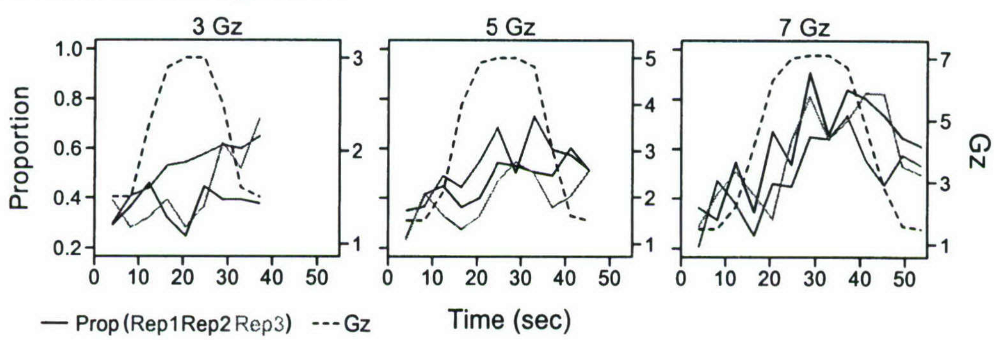

Figure 9. Proportion Greater Than 110% of Dynamic Baseline Averaged Across Subjects

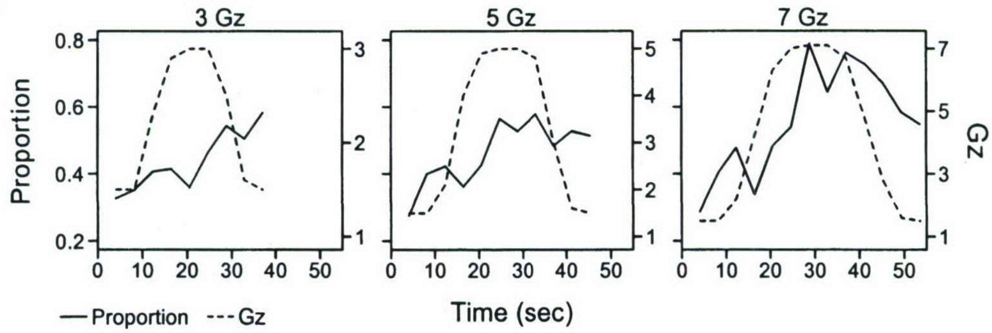

Figure 10. Proportion Greater Than 110% of Dynamic Baseline Averaged Across Subjects and Replications

Finally, the proportion of "time on target" data were calculated for the 7 G_z SACM profile. The data were averaged across subjects and replications. The results are illustrated in Figure 11.

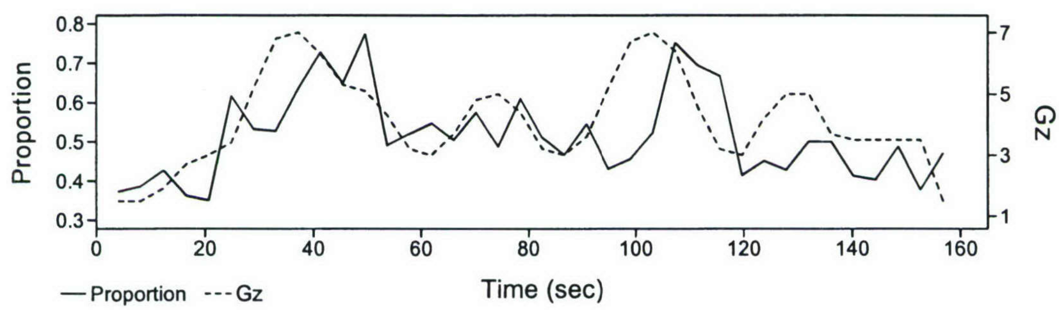

Figure 11. Proportion Greater Than 110% of Dynamic Baseline Averaged Across Subjects and Replications (SACM)

Table 1 displays the values used in the creation of Figure 7, whereas Table 2 displays the values used to create the plots in Figure 10. Similarly, Table 3 presents the values used to create the plots found in Figures 8 and 11.

Table 1. Mean RMSE by Time and G_z Plateau (Plotted Values in Figure 7)

Time	3 Gz		5 Gz		7 Gz	
(sec)	Gz	RMSE	Gz	RMSE	Gz	RMSE
4.1	1.5	55	1.5	52	1.5	54
8.2	1.5	58	1.5	59	1.5	63
12.3	2.3	65	2.1	62	2.2	67
16.5	2.9	61	4.0	54	4.2	55
20.6	3.0	54	4.9	62	6.3	70
24.7	3.0	69	5.0	78	7.0	73
28.8	2.5	72	5.0	77	7.1	119
33.0	1.6	60	4.8	81	7.1	105
37.1	1.5	83	3.0	74	6.7	114
41.2			1.6	73	4.8	111
45.3			1.5	71	2.8	100
49.5					1.6	81
53.6					1.5	75

Table 2. Mean Proportion Greater Than 110% of Dynamic Baseline by Time and G_z Plateau (Plotted Values in Figure 10)

Time	3 Gz		5 Gz		7 Gz	
(sec)	Gz	Prop	Gz	Prop	Gz	Prop
4.1	1.5	0.33	1.5	0.28	1.5	0.29
8.2	1.5	0.35	1.5	0.40	1.5	0.40
12.3	2.3	0.41	2.1	0.42	2.2	0.48
16.5	2.9	0.41	4.0	0.36	4.2	0.34
20.6	3.0	0.36	4.9	0.43	6.3	0.48
24.7	3.0	0.46	5.0	0.56	7.0	0.54
28.8	2.5	0.54	5.0	0.53	7.1	0.79
33.0	1.6	0.50	4.8	0.58	7.1	0.64
37.1	1.5	0.58	3.0	0.48	6.7	0.76
41.2			1.6	0.53	4.8	0.73
45.3			1.5	0.51	2.8	0.67
49.5					1.6	0.58
53.6					1.5	0.55

Table 3. RMSE and Proportion Greater Than 100% of Dynamic Baseline Averaged Across Subjects and Replications (Plotted Values in Figures 8 and 11)

Time (sec)	Gz	RMSE	Proportion		Time (sec)	Gz	RMSE	Proportion
4.1	1.5	59	0.37		111.4	4.6	119	0.70
8.3	1.5	61	0.39		115.5	3.2	105	0.67
12.4	1.9	72	0.43		119.6	3.0	73	0.41
16.5	2.7	61	0.36		123.8	4.2	76	0.45
20.6	3.0	60	0.35		127.9	5.0	68	0.43
24.8	3.4	81	0.62		132.0	5.0	74	0.50
28.9	5.2	78	0.53		136.1	3.7	75	0.50
33.0	6.8	86	0.53		140.3	3.5	67	0.41
37.1	7.0	81	0.64		144.4	3.5	71	0.40
41.3	6.3	95	0.73		148.5	3.5	72	0.49
45.4	5.3	104	0.65		152.6	3.5	65	0.38
49.5	5.1	108	0.77		156.8	1.5	66	0.47
53.6	4.3	83	0.49					
57.8	3.2	85	0.52					
61.9	3.0	87	0.55					
66.0	3.7	72	0.51					
70.1	4.8	94	0.57					
74.3	5.0	80	0.49					
78.4	4.4	75	0.61					
82.5	3.2	84	0.51					
86.6	3.0	82	0.47					
90.8	3.6	87	0.55					
94.9	5.2	70	0.43					
99.0	6.7	66	0.46					
103.1	7.0	75	0.52					
107.3	6.4	114	0.75					

Figures 12, 13, 14, and 15 show the percent change in tracking performance from the baseline level. Figure 12 displays the performance changes during the 3 G profile, Figure 13 illustrates the performance changes during the 5 G profile, and so on.

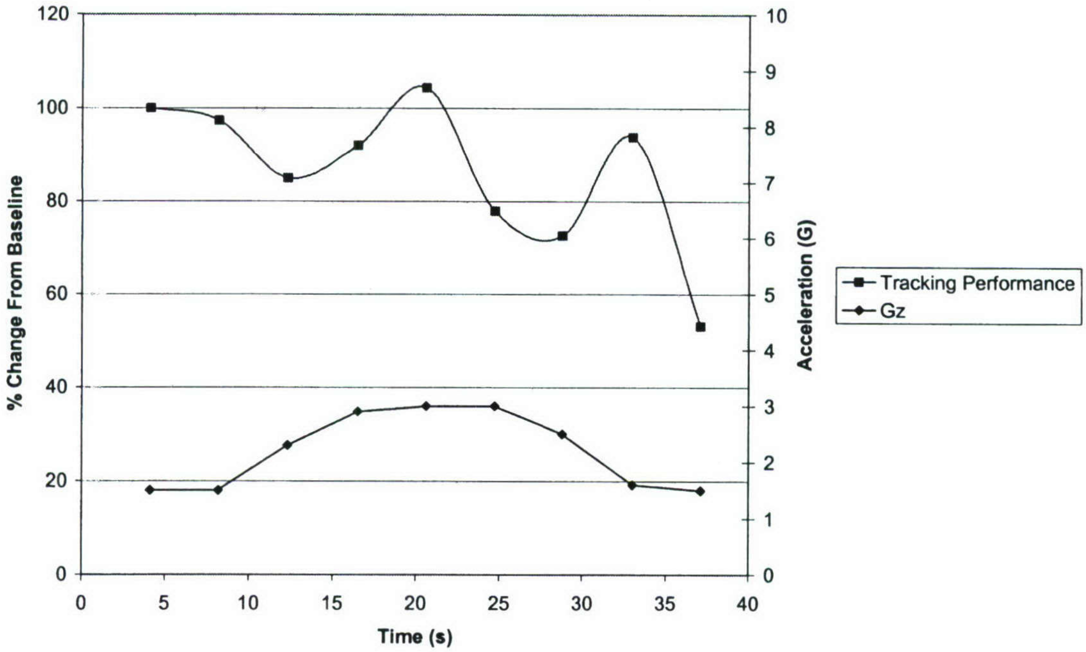

Figure 12. Average RMSE Percent Change From Baseline for 3 G_z Plateau

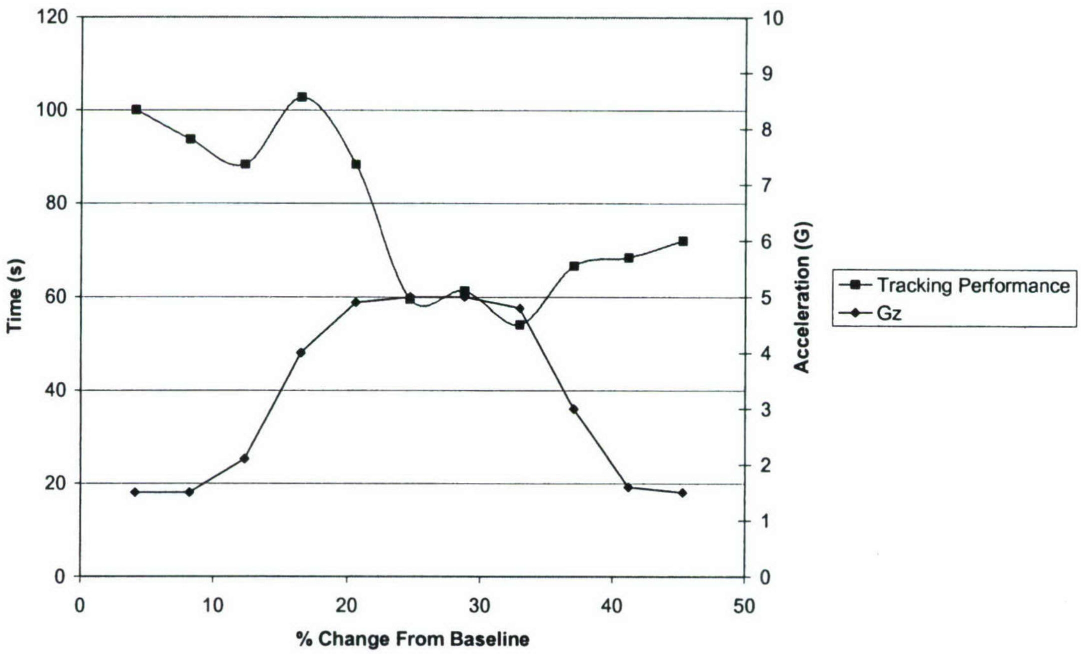

Figure 13. Average RMSE Percent Change From Baseline for 5 G_z Plateau

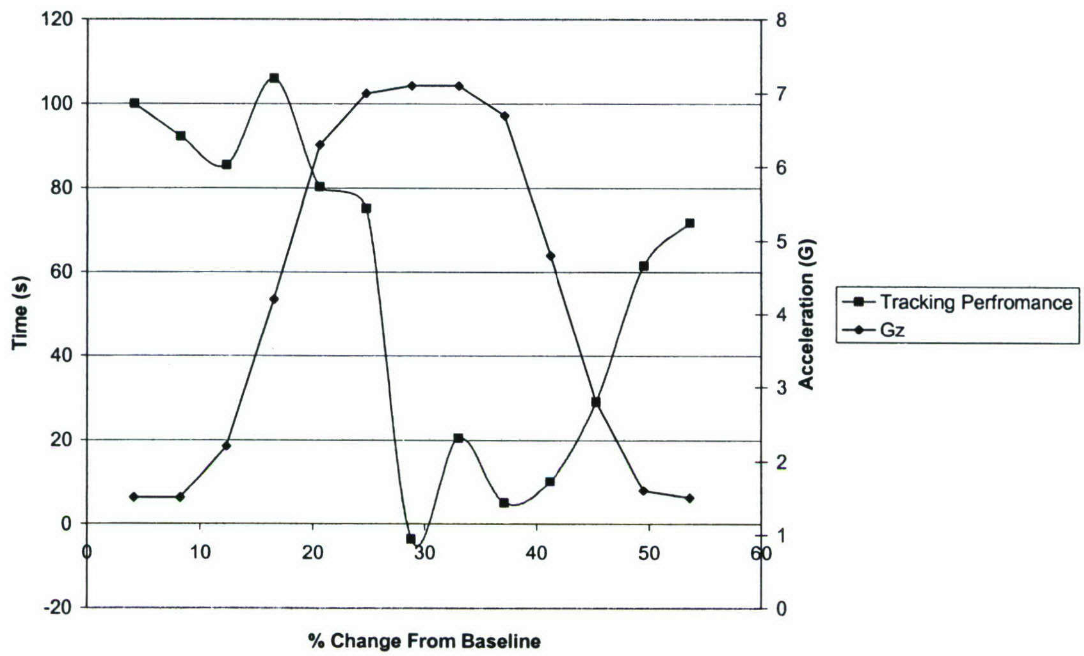

Figure 14. Average RMSE Percent Change From Baseline for 7 G_z Plateau

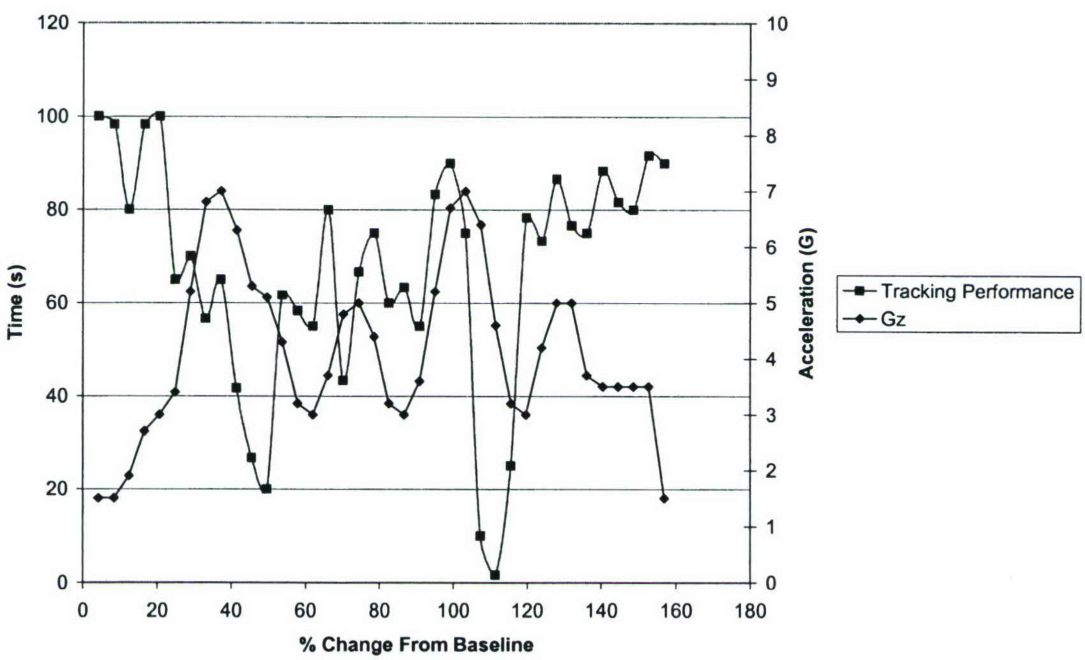

Figure 15. Average RMSE Percent Change From Baseline for 7 G_z SACM

The model predictions of tracking performance were compared to the measured data. Plots can be found in Figures 16-19.

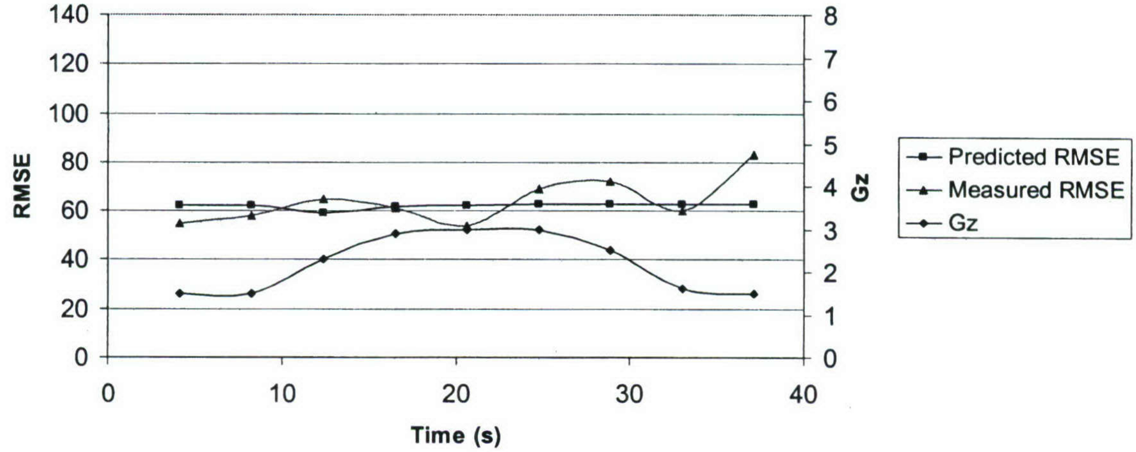

Figure 16. Measured and Predicted Tracking RMSE for 3 G_z Plateau

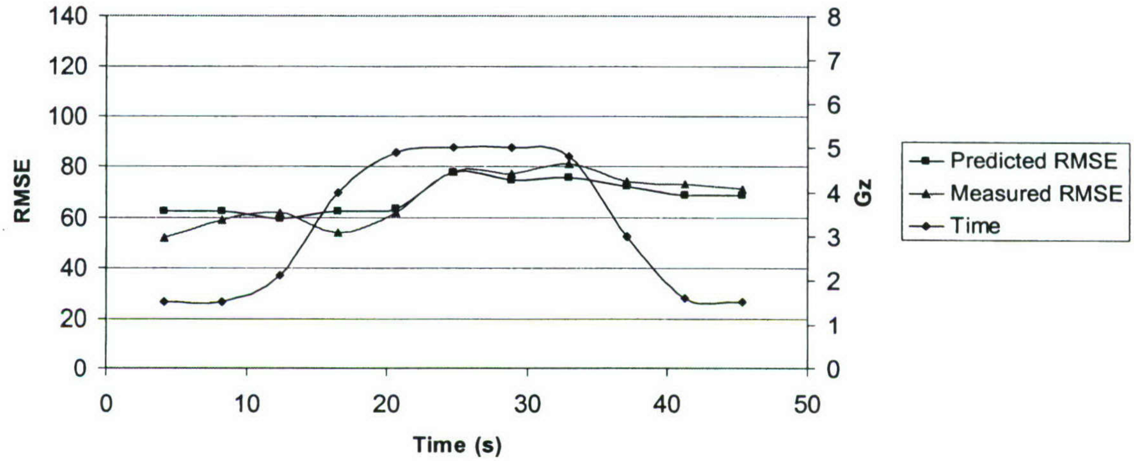

Figure 17. Measured and Predicted Tracking RMSE for 5 G_z Plateau

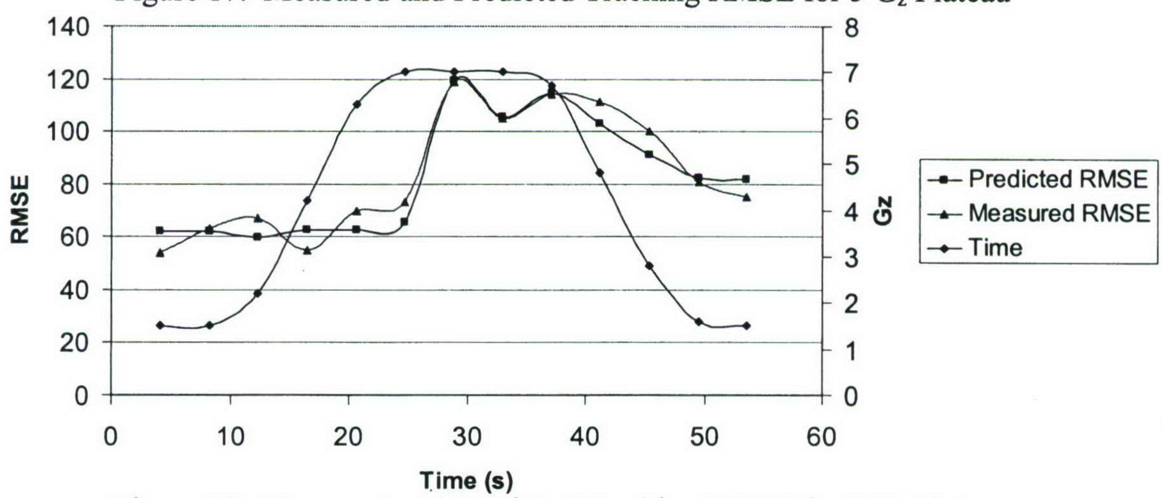

Figure 18. Measured and Predicted Tracking RMSE for 7 G_z Plateau

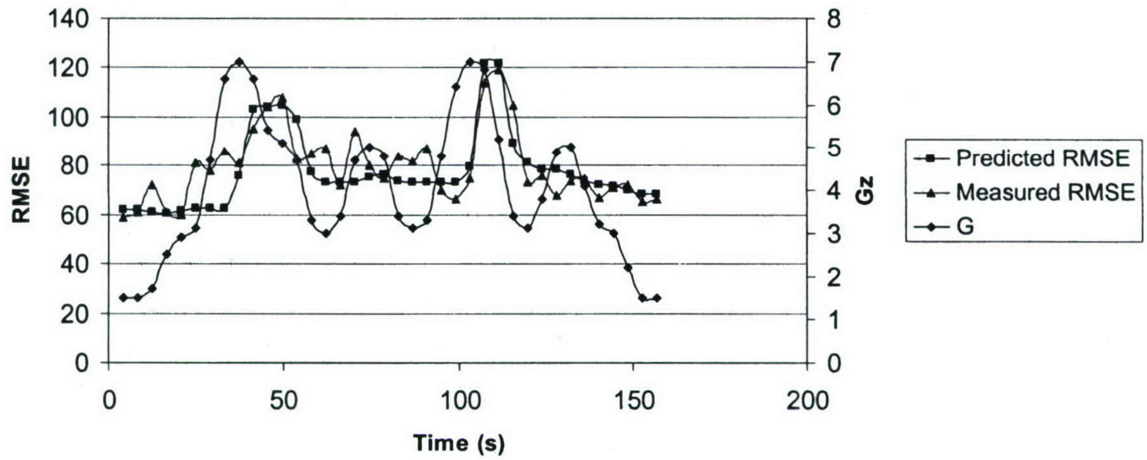

Figure 19. Measured and Predicted Tracking RMSE for 7 G_z SACM

Table 4 (below) shows the agreement results for the tracking performance model. The calculations included correlation coefficients, best-fit slopes (on a plot of measured vs. predicted values), and mean absolute % error. The 3 G_z profile was omitted from this table due to the fact that performance fluctuations measured at this acceleration were minimal. From Figure 14, one can see that the model simply predicts a single value for accelerations that are 3 G_z or lower. This value represents the average RMSE of the sinusoidal tracking performance plot measured at 3 G_z. Correlation coefficients between a sinusoidal line and a straight line would be misleading. Table 4 also emphasizes that the 7 G_z profile boasted the highest agreement, followed closely by the 5 G_z profile.

Table 4. Agreement Results between Measured and Predicted Values

	Correlation Coefficient	**Best-Fit Slope**	**Mean Absolute % Error**
5 G_z	0.91	1.04	6%
7 G_z	0.96	0.99	7%
7 G_z SACM	0.82	0.78	8%

DISCUSSION AND CONCLUSIONS

The level of cognitive function and performance can greatly influence the outcome of an air combat mission. The ability to successfully navigate the aircraft, make critical decisions, recall procedures from memory, track a target, correctly perceive motion, and maintain situational awareness can all be affected by decreases in cognitive performance. Evidence has been shown previously by Tripp et al. that reduced arterial blood flow to the brain is one of the principal causes for these reductions in cognitive task performance (**11, 12**). This is mainly due to the fact that the brain requires a large amount of energy (obtained through aerobic processes) to operate at normal levels. Without oxygen, glucose metabolism is decreased, producing far less usable energy. Hence, higher-order cognitive processes are sacrificed to maintain critical life-preserving functions. The extent of these decrements and the subsequent ability to create an

operationally relevant model are the current focus of study. Such a model would prove to enhance the wargaming and simulation software currently employed.

The results of this study show statistically significant ($p \leq 0.05$) decreases in tracking performance as the acceleration level increases. This is denoted primarily by the increases in RMS error which correspond to the target aircraft becoming further away from the crosshairs of the subject's aircraft. However, the calculated significant RMSE increases during the 3 G_z plateau may not be meaningful because the largest increases occurred after the G_z exposure was over. This was most likely caused by subjects prematurely arresting their performance on the task, mistakenly believing that data collection was over and the 1-minute rest period had begun. Negating this final extraneous data point for the 3 G_z profile, task performance only degraded approximately 25% at the peak. Performance degraded by about 40% during the 5 G_z plateau and approximately 100% during the 7 G_z plateau. The results also show that the proportion of "time on target" means followed the same trend as the RMSE. These data reveal that pilots lose much of their ability to successfully and accurately track a target at G levels of approximately 7 or above when protected in the standard anti-G suit, only. Even at 5 G_z, their ability to track has degraded to a degree that would start to produce serious problems in successfully aligning the target in their crosshairs.

Although it is interesting to discover the magnitude of cognitive performance decrements for various discrete, single-peak G_z profiles, it does not represent the majority of the acceleration profiles pilots generally experience during combat engagements. Therefore, it is perhaps more operationally relevant to investigate performance trends over time with multiple G_z peaks at various levels. To accomplish this objective, the 7 G_z SACM was employed in this study. Perhaps one of the more interesting results from the data analysis is that the tracking performance is degraded to a greater extent for subsequent peaks to high ($\geq$7) G_z levels. This is most likely a product of several phenomena. Primarily, the SACM contained G_z levels and durations sufficient to produce significant levels of fatigue. This would most certainly lead to further decrements to the performance on the task.

In addition, oxygen dissociation in the cerebral tissue frequently continues to persist even at relatively low G_z levels (including accelerations as low as 3 G_z) during long, multiple-peak profiles (**13**). That is to say, large recoveries in cerebral oxygen saturation (rSO_2) do not take place until the acceleration has reached a level close to 1 G_z. The trend for rSO_2 in protected subjects (those equipped with a G-suit and who use the anti-G straining maneuver) during a SACM is a slow linear decay throughout the entire profile. This is most likely a result of the fact that even at 3 G_z, the eye-level blood pressure could be degraded by as much as 66 mmHg (**6**). Consequently, a considerable reduction in oxygenated blood delivered to the cerebral tissue remains. However, the brain continues to use the same amount of energy (hence oxygen) at 3-7 G_z as it used at 1 G_z. Therefore, oxygen continues to dissociate from the cerebral tissue to combine with glucose to be converted into usable energy in the form of ATP. Based on this information, it is reasonable to conclude that the greater degree of depleted oxygen in the cerebral tissue at the second 7 G peak contributed to the greater decrease in tracking performance due to the fact that less energy was available for the higher-order cognitive ability.

The agreement results reveal that the model is a very accurate predictor of tracking performance at various G_z levels. The 7 G_z profile boasted the highest agreement, followed closely by the 5 G_z profile. Although the lowest agreement was found in the 7 G_z SACM, all the G_z profiles tested in this study showed good overall agreement with the model.

However, it should be noted that a model, by definition, covers only some aspects of the system it represents. Therefore, it is only applicable in the specific range of conditions for which it was constructed (**6**). Consequently, the tracking performance model should only be used to investigate changes in tracking performance caused by accelerations between 1 and 7 G_z. The subjects modeled were equipped with G-suits and utilized the L-1 anti-G straining maneuver. Thus, no conjectures should be made as to performance changes experienced by subjects without one or both of these G protective measures based on the output of this model. Although this model has been verified for G levels between 1 and 7 G_z, it has not yet been validated. In addition, performance measurements have not yet been completed for various acceleration onset rates. Therefore, the model has not yet been verified for onset rates above 1 G_z/sec. A comparison with data collected at higher onset rates (6 G_z/sec) is planned for the near future. Finally, this model represents only the first in a series of twelve performance tasks. Only after all twelve experiments are completed will a more comprehensive model of cognitive performance changes due to the stress of the high-G_z environment be available.

This model can be useful in several applications within the flight community. Primarily, a model of a pilot's ability to successfully pursue and track a target aircraft would be advantageous when planning air combat missions. Currently, none of the flight simulations accounts for these changes. Theoretically, a simulated pilot could achieve 9 G_z for extended periods of time repeatedly without the associated decreases in cognitive ability and performance. This is likely to skew the outcome of the simulated mission and present unachievable results. Thus, mission planners should have a validated model that can accurately predict the effect these cognitive performance changes will have on the mission.

This cognitive performance modeling technology might also have applications for static pilot training. The software that is currently used in flight simulators does not utilize models of human performance, cognitive or otherwise. Here again, the simulated aircraft, both enemy and friendly, are capable of achieving high acceleration levels (up to 9 G_z) for extended periods of time (up to and including several minutes) without any decrements in flight performance. Likewise, the simulated aircraft can attain these high G_z levels multiple times without a sufficient rest period. The pilots being trained on these simulations encounter these same unrealistic freedoms. The software does not currently alter the response of simulation to the pilot's inputs based on the level of performance decrement they would experience in the real environment. Constructing a model of cognitive performance decrements and applying it to these simulations should produce a more realistic simulation of the flight environment, and thus produce more effective training.

The tracking performance model is a crucial first step in compiling a complete model of cognitive performance decrements that pilots experience in high G_z maneuvers. The collected data clearly illustrate the fact that cognitive performance is affected to a

great extent by high-G_z stress. Once validated, the model should prove to be extremely beneficial to providing more realistic representations of the pilot to the modeling and simulation community. This could benefit mission planners by providing a realistic depiction of acceleration stress on the overall mission. In addition, it should offer a more operationally relevant static training tool for student pilots.

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APPENDIX A: COMPLETE SUBJECT DATA

This appendix contains plots of all subject data for each of the 4 G_z profiles. The resulting RMSE, G_z, and time data from the three experimental test days were plotted for each of the eight subjects. The plots for the 3, 5, and 7 G_z 15-sec plateau profiles can be found in Figure A-1.

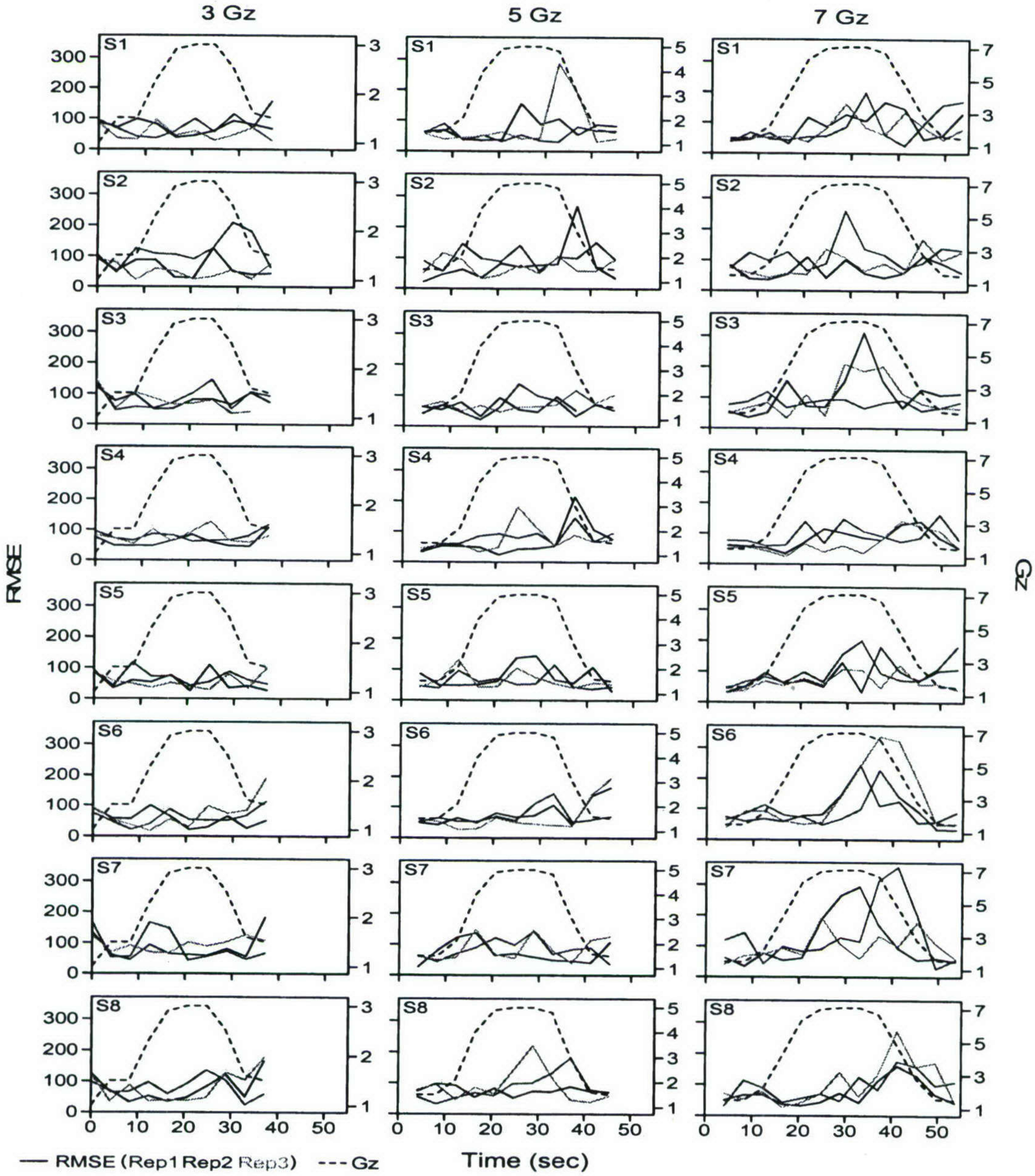

Figure A-1. RMSE for Each G_z Plateau, Subject (N = 8), and Replication

Figure A-2 displays the resulting tracking RMSE data for the SACM profile for all subjects and experimental testing days.

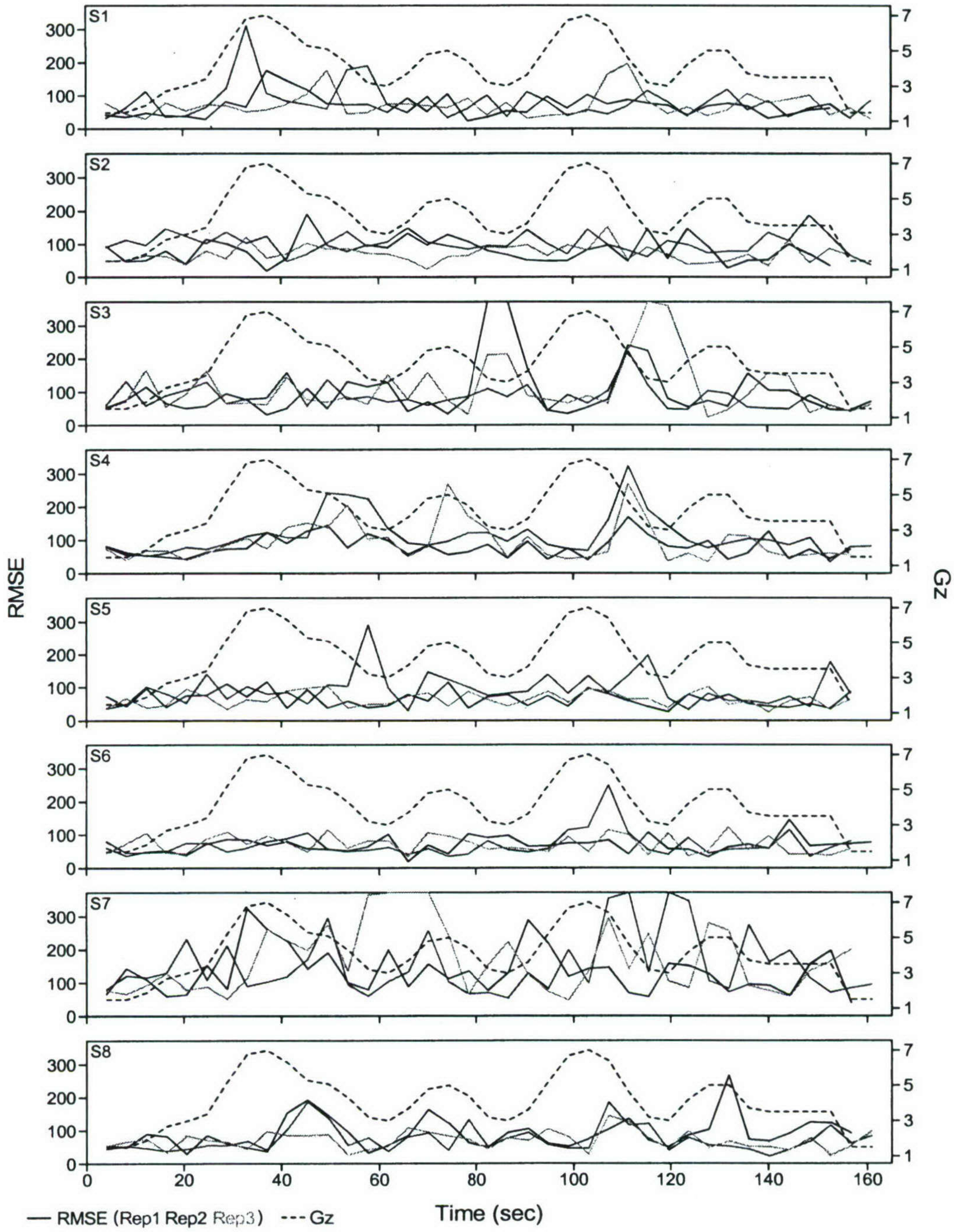

Figure A-2. RMSE during SACM for Each Subject (N = 8), and Replication

The data displayed in Figure A-3 contains the results of calculating the proportion of time that the target aircraft was being successfully tracked by the subject for each data run during the 3, 5, and 7 G_z profiles.

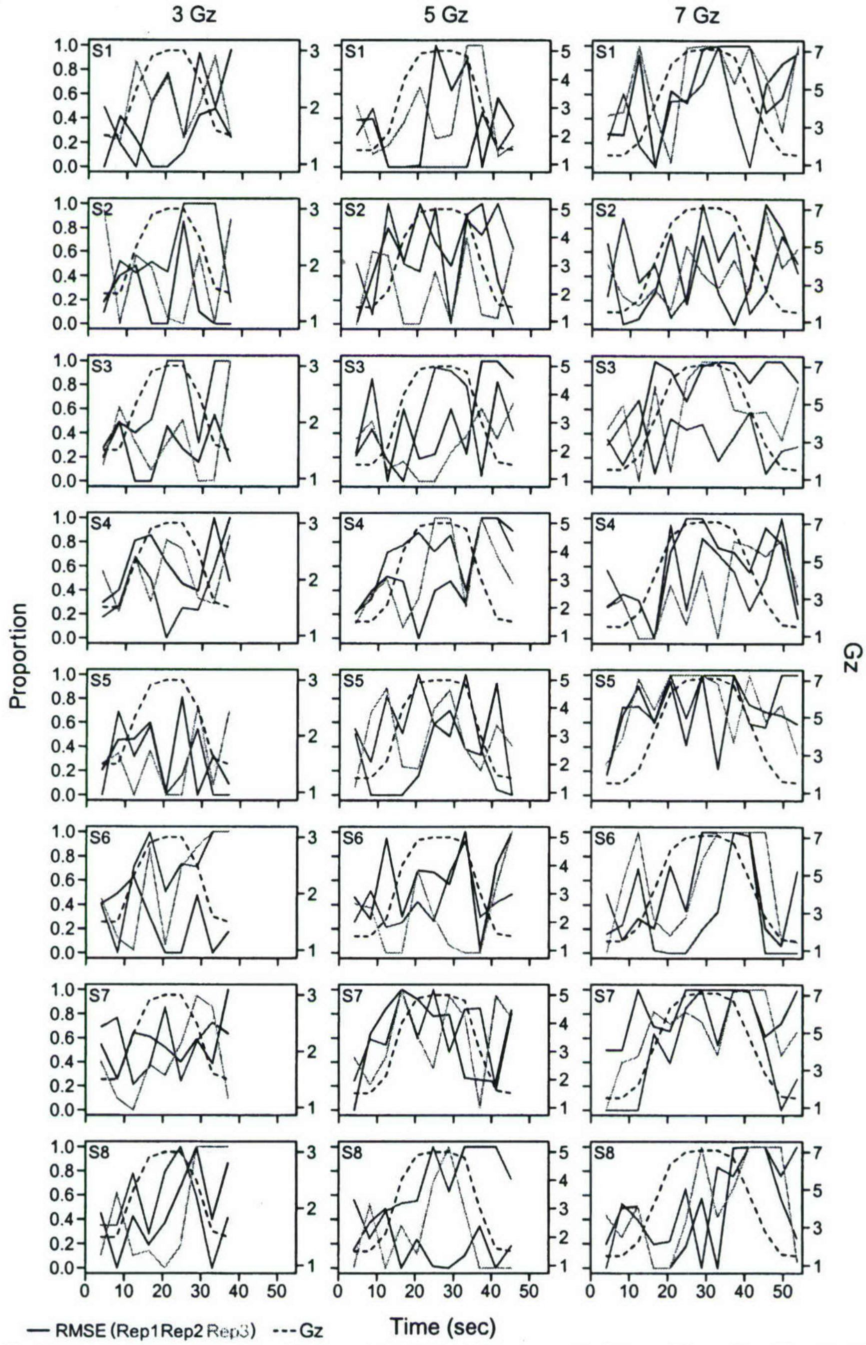

Figure A-3. Proportion Greater Than 110% of Dynamic Baseline for Each G_z Plateau, Subject (N = 8), and Replication

The results of completing the aforementioned proportion calculations for the 7 G_z SACM are displayed in Figure A-4 below.

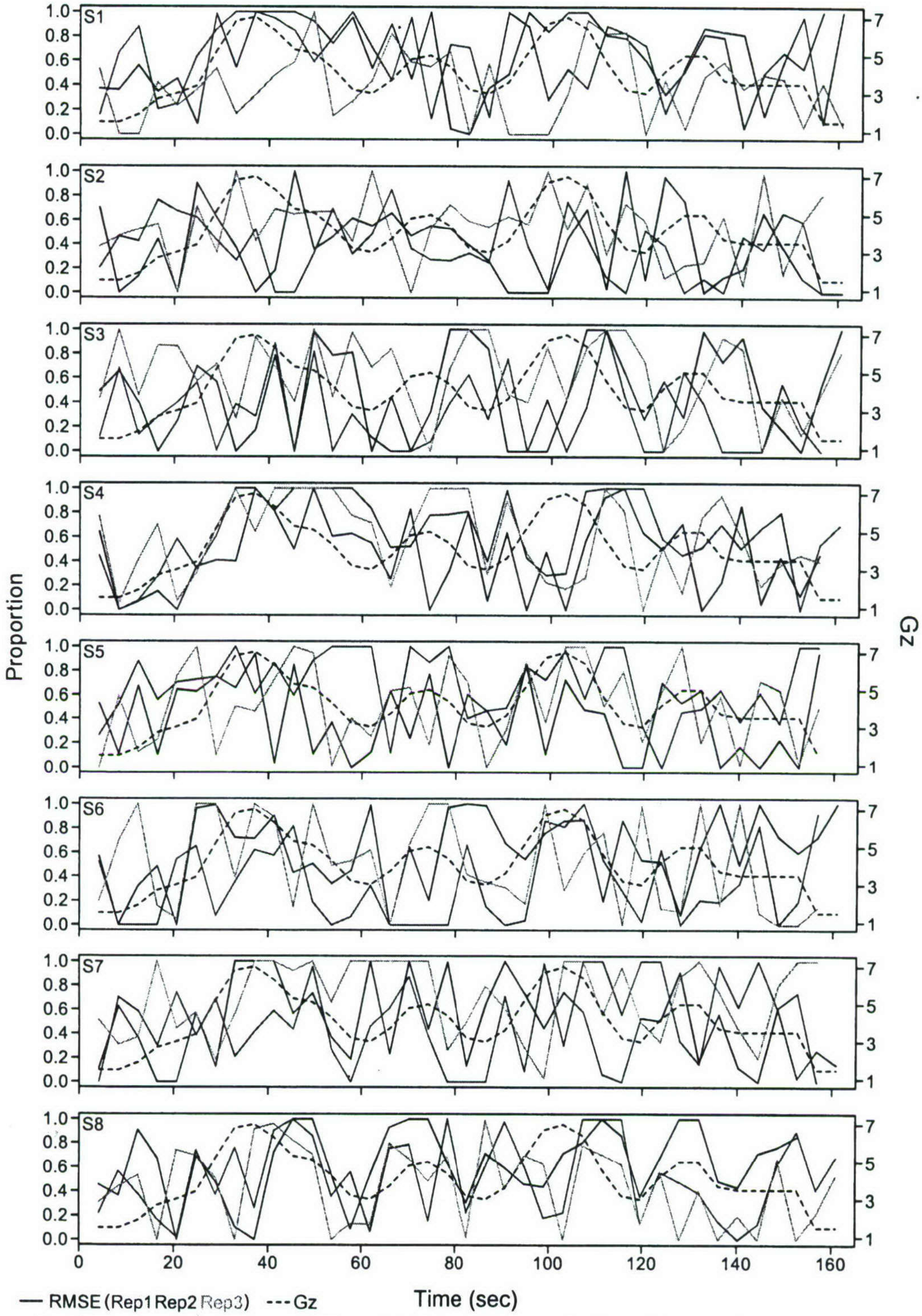

Figure A-4. Proportion Greater Than 110% of Dynamic Baseline during SACM for Each Subject (N = 8), and Replication.